(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 523 968 B1**

(12) EUROPEAN PATENT SPECIFICATION

(45) Date of publication of patent specification: **06.12.95**

(51) Int. Cl.[6]: **C23C 16/30**, C23C 16/44, G02B 1/10

(21) Application number: **92306463.8**

(22) Date of filing: **15.07.92**

(54) Process for an improved laminate of ZnSe and ZnS.

(30) Priority: **15.07.91 US 729980**

(43) Date of publication of application:
20.01.93 Bulletin 93/03

(45) Publication of the grant of the patent:
06.12.95 Bulletin 95/49

(84) Designated Contracting States:
CH DE FR GB IT LI

(56) References cited:
US-A- 4 978 577

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Description

This invention relates to a method for preparing an infra-red transmissive window that is substantially free of optical distortion. More particularly, it relates to a method for preparing a laminate of zinc selenide and zinc sulfide which overcomes the bimetallic effect arising from the different coefficients of thermal expansion of the two layers. The IR window made by this invention meets the demands of certain applications for which the prior art windows were either unsuitable or prohibitively expensive.

An improved method for the chemical vapor deposition of zinc sulfide on a zinc selenide substrate is taught in US-A-4,978,577. There, the substrate is heated in the presence of H_2S and the absence of zinc vapor for a certain period of time before the zinc vapor is introduced into the heating chamber. The adhesion of the zinc sulfide to the substrate is greatly improved by that treatment. A problem inherent in the high temperature lamination of materials having different coefficients of thermal expansion is the bowing of the laminate in response to the stress sometimes referred to as "the bimetallic effect." The deposition of the zinc sulfide occurs at a temperature of about 700°C. As the laminate is cooled to room temperature, the initially flat upper surface of the zinc selenide substrate becomes convex and the contiguous surface of the zinc sulfide is, perforce, concave. If the substrate is mounted in the heating chamber in such a way that it can not expand and contract freely, the bowing will not be symmetrical and will be extremely difficult to correct by optical grinding methods.

Infra-red transmissive windows made from such bowed laminates are difficult to use in wide-angle "forward looking infra-red imager" systems because of the optical path differences (OPD) for the light rays that pass through the window at different angles to the surface. As the angle of incidence grows larger, the OPD becomes greater. An optician can reduce the OPD by introducing some curvature into the outer surfaces of the laminate to compensate for the interfacial curvature. This is a lengthy and costly process, especially when the curvature is unsymmetrical. Thus, the bowing phenomenon is a deterrent to the widespread application of the ZnSe/ZnS laminate as an infra-red window.

The present invention consists in an infrared optical element comprising a ZnSe substrate having a ZnS layer deposited on its surface by chemical vapor deposition, wherein the interface is sufficiently planar that the transmitted wave front aberration for waves that are not normal to the surface of the optical element is less than 0.1 of a wavelength for rays 40-60° from normal.

According to a further aspect of this invention, there is provided a laminated structure comprising layers of ZnSe and ZnS which has been heated to a temperature of about 700°C and has an interface between the layers, which interface is sufficiently planar that the transmitted wavefront aberration for waves that are not normal to the surface of the structure is less than 0.1 of a wavelength for rays 40-60° from normal.

By means of the invention there can be provided a laminate of ZnS and ZnSe that needs no optical correction even though the laminate was made by chemical vapour deposition of the sulfide onto the selenide. A "diffraction limited" optical system can thus be made.

The optical element of the invention can be made by establishing a heating and cooling regimen for the chemical vapor deposition, determining the curvature of the interface between the substrate and the deposit which will occur during the cooling phase of said regimen, imparting the negative of that curvature to the surface of the substrate upon which the zinc sulfide is to be deposited, heating the substrate in a chemical vapor deposition chamber, coating that surface with the sulfide by chemical vapor deposition, and cooling the resulting laminate.

For carrying out the above method the invention provides a chemical vapor deposition apparatus comprising a furnace, a mandrel box mounted within the furnace and defining a vapor deposition zone, the box comprising a mandrel plate having a passage therein communicating with the deposition zone, a substrate holding frame removably mounted on said mandrel plate in overlapping relation to the passage and having an opening therein in alignment with said mandrel plate passage, and a back plate removably mounted on the holding frame plate as a closure for the opening, characterised in that the holding frame forms part of a restraint-free substrate holding frame and back plate assembly and has lips projecting toward each other from opposite boundaries of the opening, between the deposition zone and the back plate, the lips being adapted for support of a substrate to be placed in the opening, said opening otherwise being larger than the substrate to be placed therein and the distance between the lips and the back plate being larger than the thickness of the substrate.

The holding frame allows free lateral, longitudinal, and transverse movement of the substrate so that it may expand and contract freely during and after the chemical vapor deposition of the zinc sulfide.

The amount and shape of the bowing that will occur may be calculated using modern finite-element modeling techniques since the mechanical and thermal properties of ZnSe and ZnS are well known. The calculation of stress induced by the bimetallic effect is taught by Roark, Raymond J. and Young, Warren C., "Formulas for Stress and Strain", 5th edn. McGraw-Hill, Inc., 1938, Section 10-4, pp337-381, "Bimetallic Circular Plates", particularly in case 15a and also at page 366. The bowing may also be measured by conventional optical means, e.g., interferometry.

A preferred embodiment of the invention will now be described with reference to the accompanying drawings wherein:

FIG.1 is a cross section of a laminate of the prior art.

FIG.2 is a graph of the coefficient of thermal expansion of ZnSe and ZnS at increasing temperatures.

FIG. 3 is a cross section of a substrate mounted in a frame inside a chemical vapor deposition furnace according to this invention.

FIG. 4 is a cross-section of a broken away portion of a hot vapor deposition furnace wherein ZnS is deposited on the ZnSe substrate.

FIG. 5 is a sectional view taken along line 5-5 of FIG. 4.

FIG. 6 is graph of the sag of a ZnSe/ZnS laminate of the prior art.

FIG. 7 is a cross section of the laminate of this invention after deposition of the ZnS and cooling.

DETAILED DESCRIPTION OF THE INVENTION

In FIG. 1, the ZnSe substrate 10 is bowed upward and is seen to have a convex upper surface 12 and a concave lower surface 14. The ZnS layer 16 is bowed in like manner. The amount of sag is shown at 18 by the dimension lines depicting the highest and lowest points of the curved surface.

The relation between the coefficient of thermal expansion and the temperature for both the ZnSe and the ZnS is shown in FIG. 2.

In FIG. 3 H_2S is introduced into the mandrel box 20 through the pipe 21 to contact the ZnSe substrate 22 in the absence of zinc vapor while the zinc metal 23 is being heated in the pots 24 and when the zinc reaches its vaporization temperature, the vapor flows through the ports 26 into the deposition zone 27. The mandrel box 20 is mounted upright in the furnace 28 between the heating elements 29. The box is made up of graphite plates, including the plates 30 and 31 shown here. The substrate holding frame 32 is mounted on the mandrel plate 31 in defining relation to the passage 33 through the plate 31 to place the substrate within the passage where it may be exposed to the vapors in the zone 27. As shown in larger detail in FIGS. 4 and 5, the opening 34 in the frame 32 is larger in each dimension than the substrate and the distance between a lip 35 and the back plate 36 is greater than the thickness of the substrate. A restraint-free assembly is thus made a part of the furnace 28 so that the bowing of the laminate upon cooling will be symmetrical and can be remedied by the method of this invention. The lips 35, which project toward each other from opposite boundaries of the opening 34 and are integral parts of the holding frame 32, are adapted to the support of the substrate in,an upright position while blocking off only a minimal portion of the passage 33 for vapors traveling toward the substrate.

In like manner, the shields 37 are integral parts of the mandrel plate 31 which project toward each into the deposition zone from opposite boundaries of the passage 33. They are superposed over the outer periphery of the frame 32 to provide a shadowing effect whereby the deposition of ZnS in the recess 38 of the mandrel plate and in the corners between the frame and the plate is limited. The propagation of cracks from a ZnS coating 40 on the mandrel plate 31 and the shield 37 into the desired overcoat 39 on the substrate 22 is thereby minimized by isolation of the overcoat from the deposits 40.

The amount and location of the bowing that would occur during the deposition of ZnS onto a ZnSe substrate are shown in FIG. 6. The substrate is 18.3 cm (7.2 inches) long, 14 cm (5.5 inches) wide, and 1.8 cm (0.70 inch) thick; the thickness of the ZnS is to be 3.2 mm (0.125 inch). Using the ANSYS® finite element analysis program of Swanson Analysis Systems,Inc. on an ARIES ConceptStation® (Aries Technology,Inc.), the sag is calculated to be 78 μm. and symmetrical about the center of the laminate. From the results of that calculation and in accordance with this invention, a ZnSe substrate is ground and lapped to produce a blank having a concave spherical surface with a total sag of 78 μm. The blank is then mounted in the box 20 of FIG. 3 and that assembly is placed in the vapor deposition zone 27 and ZnS is deposited on the substrate at about 700°C as described in U.S. Patent No. 4,978,577. Upon cooling to room temperature, the laminate has a flat interface as shown at 41 in FIG. 7. The curvature that had been imparted to the substrate mechanically is cancelled by the bimetallic effect being put to work for us instead of against us.

The following computer program may also be used to calculate the center sag of a laminate to be made by chemical vapor deposition of ZnS on a ZnSe substrate:

30 REM: This is a program to calculate maximum

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deflection and stress in a ZnS/ZnSe
40 REM: Window subjected to a change in temperature
50 REM: The equations used are from Roark
55 REM: ZnS is material 1, (top layer); ZnSe is material 2 (bottom layer)
60 REM: Following are the variables used
70 REM: A - radius of plate in inches
80 REM: A1 - thermal expansion coef. of material 1 in inch/inch C
90 REM: A2 - Thermal expansion coef. of material 2 in inch/inch C
100 REM: DT - Temperature gradient in degrees C
110 REM: T1 - Thickness of material 1 in inches
120 REM: T2 - Thickness of material 2 in inches
130 REM: E1 - Modulus of material 1 in psi
140 REM: E2 - Modulus of material 2 in psi
150 REM: K1P - Derived constant
160 REM: V1 - Poisson's ratio of material 1
170 REM: V2 - Poisson's ratio of material 2
180 REM: KYC - Loading constant from Roark
310 LET A1=7.700001E-06
320 LET A2=8.300001E-06
330 INPUT "Temperature gradient"; DT
340 INPUT "Thickness of ZnS (material 1) in inches"; T1
350 INPUT "Thickness of ZnSe (material 2) in inches"; T2
360 LET E1=1.08E+07
370 LET E2=9750000!
380 LET V1=.29
390 LET V2=.28
400 LET KYC=.5
410 LET K1P=4+(6*T1/T2)+(4*(T1/T2)^2)+-(E1*T1^3*(1-V2))/(E2*T2^3*(1-V1))+(E2*T2*(1-V1)-)/(E1*T1*(1-V2))
413 LET K2P=(1+((E2*T2^3*(1-V1^2))/-(E1*T1^3*(1-V2^2)))+((3*(1-V1^2)*(1+T2/T1)-^2*(1+(E1*T1)/(E2*T2)))/((1+E1*T1/(E2*T2))^2-(V1+(V2*E1*T1)/(E2*T2))^2)))
416 LET K3P=(1+((V2*E2*T2^3*(1-V2^2))/-(V1*E1*T1^3*(1-V1^2)))+((3*(1-V1^2)*(1+T2/T1)-^2*(1+(V2*E1*T1/(V1*T2*E2))))/((1+(E1*T1/E2*T2))-)^2-(V1+(V2*E1*T1/(E2*T2)))^2)))
420 LET X = (6*(A2-A1)*DT*(T1+T2))/(K1P*T2^2)
425 INPUT "Enter plate radius in inches"; A
427 REM: Calculate center deflection
430 LET Y = KYC*X*A^2
500 PRINT
510 PRINT
520 PRINT "ZnSe Thickness";T2;" inches","ZnS thickness";T1;" inches"
521 PRINT
522 PRINT "Plate radius";A;" inches","temperature gradient"; DT;" degrees C"
523 PRINT
530 PRINT "The maximum deflection is ";Y;" inches"
532 REM: Calculate stresses associated with deflection
535 LET VE = V1*(K3P/K2P)
540 LET DE = (E1*K2P*T1^3)/(1-V1^2))
545 LET L8 = .5*(1+VE)
550 LET M = DE*X*(1-VE)*(1-L8)
560 LET S1 = ((-1)*6*M/(T1^2*K2P))*(1+(((1-V1^2)*(1+T2/T1)*(1+(E1*T1/(E2*T2)))) ((1+-(E1*T1/(E2*T2)))^2-(V1+(V2*E1*T1)/(E2*T2)))^2)))-((A2-A1)*DT*E1/((1-V1)*K1P*(3*T1/T2+2*(T1/T2)^2-((E2*T2*(1-V1))/(E1*T1*(1-V2)))))
563 LET S2A = E2*T2*(1-V1^2)/(E1*T1*(1-V2^2))
565 LET S2N = (1-V1^2)*(1+T2/T1)*(1+E1*T1/-(E2*T2))
567 LET S2D = (1+E1*T1/(E2*T2))^2-(V1+V2*E1*T1/(E2*T2))^2
568 LET S2S = ((A2-A1)*DT*E2)/((1-V2)*K1P)*(3*-(T1/T2)+2-((E1*T1^3*(1-V2))/(E2*T2^3*(1-V1))))
570 LET S2 = (6*M/(T1^2*K2P))*(S2A+(T1/T2)-*S2N/S2D)+S2S
575 PRINT
576 PRINT

580 PRINT "The stress of top surface of ZnS is ";S1;"PSI"
590 PRINT "The stress on bottom surface of SnSe is ";S2;"PSI"
750 END
```

NOTE: An asterisk is a multiplication sign here; ^ indicates superscript follows

A particular example of the process of this invention is as follows:

The potential center sag of the interface of a laminate window measuring 29.8 X 18.4 cm (11.75 X 7.25 inches) and having a ZnSe thickness of 1.8 cm (0.72 inch) and a ZnS thickness of 1.5 mm (0.06 inch) was calculated, using the above program, to be 22.9 μm over a 15.2 cm (6 inch) chord spanning the bowed interface. A Znse substrate having the recited dimensions was then fabricated to have a concave surface with a radius of curvature equal to -127 ± 12.7 m (-5000 ± 500 inches) and the calculated center sag on one side. The substrate was loaded into the restraint-free holding frame 32 and the assembly was mounted over the passage 33 of the plate 31 so that the concave surface would be exposed to the zinc and H_2S vapors in the zone 27. After the substrate was coated with the ZnS to the desired thickness of 15 mm (0.06 inch) and the laminate was cooled, the window was ground flat on the top and bottom surfaces to the proper thicknesses. The radius of curvature of the interface was measured as -8830 m (-347,640 inches) and the center sag was -0.3 μm over the 15.2 cm (6 inch) span. Thus, the bowing of the interface was reduced more than 98 %.

The method of this invention places no limits on the dimensions of the window that may be produced -- one measuring 46.7 X 30.5 cm (18 X 12 inches) having been fabricated by it -- but as a practical matter the larger the window the thicker it must be for rigidity. Because its transmission in the infra-red is poorer than that of the ZnSe, the thickness of the ZnS layer on the final window should be no greater than what is required for its function as a protector of the substrate against erosion by rain and dust particles at high speeds. The minimal thickness for that protection is about 0.76 mm, 0.030 inch. The actual thickness deposited, however, will be considerably greater, i.e., about 2.54 mm, 0.10 inch, to allow for the optical grinding and polishing that is necessary to provide the desired window.

The window prepared by the method of this invention is essentially "diffraction limited", the optimal condition when one is considering the distortion of an image by an optical system. The transmitted wave front aberration for rays that are not normal to the surface of the window prepared according to this invention is less than 0.1 of a wavelength for rays 40-60° from normal. In contrast, the window having the curved interface caused by the bimetallic effect gave aberrations in the range of 0.3-0.7 wavelength in the infra-red (i.e., one wavelength = 10.6µm).

Claims

1. An infrared optical element comprising a ZnSe substrate (22) having a ZnS layer (39) deposited on its surface by chemical vapor deposition, wherein the interface (41) is sufficiently planar that the transmitted wavefront aberration for waves that are not normal to the surface of the optical element is less than 0.1 of a wavelength for rays 40-60° from normal.

2. An optical element according to claim 1 wherein the thickness of the ZnS layer (39) is at least 0.76 mm (0.03 inch).

3. A laminated structure comprising layers of ZnSe (22) and ZnS (39) which has been heated to a temperature of about 700°C and has an interface (41) between the layers, which interface is sufficiently planar that the transmitted wavefront aberration for waves that are not normal to the surface of the structure is less than 0.1 of a wavelength for rays 40-60° from normal.

4. A method for the preparation of an infrared optical element by chemical vapor deposition of ZnS on a ZnSe substrate (22) at high temperature which eliminates the curvature of the interface (41) caused by the unequal coefficients of thermal expansion for the ZnS and ZnSe, characterised by the steps of

   establishing a heating and cooling regimen for the chemical vapor deposition;

   determining the curvature of the interface (41) during said regimen;

   imparting the negative of that curvature to the surface of the substrate destined to be in contact with the ZnS; and

   coating the substrate with ZnS by chemical vapor deposition;

   whereby the interface obtained between the ZnSe and ZnS is sufficiently flat that the transmitted wavefront aberration for waves that are not normal to the surface of the optical element is less than 0.1 of a wavelength for rays 40-60° from normal.

5. A method according to claim 4 wherein the substrate is mounted before the deposition in a manner which is free from longitudinal, lateral and transverse restraint.

6. A chemical vapor deposition apparatus comprising a furnace (28), a mandrel box (20) mounted within the furnace and defining a vapor deposition zone (27), the box comprising a mandrel plate (31) having a passage (33) therein communicating with the deposition zone, a substrate holding frame (32) removably mounted on said mandrel plate in overlapping relation to the passage and having an opening (34) therein in alignment with said mandrel plate passage, and a back plate (36) removably mounted on the holding frame plate as a closure for the opening, characterised in that the holding frame (32) forms part of a restraint-free substrate holding frame and back plate assembly and has lips (35) projecting toward each other from opposite boundaries of the opening (34), between the deposition zone (27) and the back plate (36), the lips being adapted for support of a substrate (22) to be placed in the opening (34), said opening otherwise being larger than the substrate to be placed therein and the distance between the lips and the back plate being larger than the thickness of the substrate.

7. Apparatus according to claim 6 further characterised by shields (37) projecting toward each other from opposite boundaries of the passage (33) through the mandrel plate (31) into the deposition zone and spaced apart from the holding frame (32).

Patentansprüche

1. Infrarotoptikelement mit einem ZnSe-Substrat (22) mit einer auf seiner Oberfläche durch chemische Abscheidung aus der Dampfphase abgeschiedenen ZnS-Schicht (39), wobei die Grenzfläche (41) genügend eben ist, daß die durchgelassene Wellenfront-Abweichung für Wellen, die nicht normal zu der Oberfläche des Optikelementes sind, geringer als 0,1 einer Wellenlänge für Strahlen von 40 bis 60° von der Normalen ist.

2. Optikelement nach Anspruch 1, bei dem die Dicke der ZnS-Schicht (39) wenigstens 0,76 mm (0,03 Inch) ist.

3. Laminierte Struktur mit Schichten von ZnSe (22) und ZnS (39), welche auf eine Temperatur von etwa 700 °C erhitzt wurde und eine Grenzfläche (41) zwischen den Schichten hat, die genügend eben ist, daß die durchgelassene Wellenfront-Abweichung für Wellen, die nicht normal zu der Oberfläche der Struktur sind, weniger als 0,1 einer Wellenlänge für Strahlen von 40 bis 60° von der Normalen ist.

4. Verfahren zur Herstellung eines Infrarotoptikelementes durch chemische Abscheidung von ZnS aus der Dampfphase auf einem ZnSe-Substrat (22) bei hoher Temperatur, welches die Krümmung der Grenzfläche (41), die durch die ungleichen Wärmeausdehnungskoeffizienten für das ZnS und ZnSe verursacht wird, beseitigt, **gekennzeichnet durch** die Stufen, in denen man
für die chemische Abscheidung aus der Dampfphase ein Erhitzen und Kühlen durchführt,
dabei die Krümmung der Grenzfläche (41) bestimmt,
der Oberfläche des Substrates, die dazu bestimmt ist, in Berührung mit dem ZnS zu sein, das Negativ jener Krümmung verleiht und
das Substrat durch chemische Abscheidung als Dampfphase mit ZnS überzieht,
wobei die zwischen dem ZnSe und ZnS erhaltene Grenzfläche genügend flach ist, daß die durchgelassene Wellenfront-Abweichung für Wellen, die nicht normal zu der Oberfläche des Optikelementes sind, geringer als 0,1 einer Wellenlänge für Strahlen von 40 bis 60° von der Normalen ist.

5. Verfahren nach Anspruch 4, bei dem man das Substrat vor der Abscheidung in einer Weise befestigt, die frei von Längs-, Seiten- und Querzwängen ist.

6. Vorrichtung zur chemischen Abscheidung aus der Dampfphase mit einem Ofen (28), einem in dem Ofen angeordneten und eine Zone für die Abscheidung aus der Dampfphase (27) begrenzenden Formkernkasten (20), wobei der Kasten eine Formkernplatte (31) mit einem Durchgang (33) darin, der in Verbindung mit der Abscheidungszone steht, umfaßt, einem Substrathalterungsrahmen (32), der entfernbar auf der Formkernplatte in überlappender Beziehung zu dem Durchgang angeordnet ist und eine Öffnung (34) darin in Ausrichtung mit dem Formkernplattendurchgang hat, und einer Rükkenplatte (36), die entfernbar auf der Halterungsrahmenplatte als ein Verschluß für die Öffnung angeordnet ist, **dadurch gekennzeichnet**, daß der Halterungsrahmen (32) Teil einer zwangsfreien Substrathalterungsrahmen- und Rückenplattenanordnung bildet und Lippen (35), die sich von einander gegenüberliegenden Grenzen der Öffnung (34) zueinander erstrecken, zwischen der Abscheidungszone (27) und der Rückenplatte (36) hat, wobei die Lippen zum Unterstützen eines Substrates (22), um in der Öffnung (34) plaziert zu werden, ausgebildet sind, die Öffnung im übrigen größer als das darin zu plazierende Substrat ist und der Abstand zwischen den Lippen und der Rückenplatte größer als die Dicke des Substrates ist.

7. Vorrichtung nach Anspruch 6, weiterhin **gekennzeichnet durch** Abschirmungen (37), die von einander gegenüberliegenden Grenzen des Durchgangs (33) durch die Formkernplatte (31) in die Abscheidungszone zueinander vorspringen und einen Abstand von dem Halterungsrahmen (32) haben.

Revendications

1. Elément optique infrarouge comprenant un substrat (22) de ZnSe ayant une couche (39) de ZnS déposée à sa surface par dépôt chimique en phase vapeur, dans lequel l'interface (41) est suffisamment plane pour que l'aberration du front d'onde transmis pour les ondes qui ne sont pas perpendiculaires à la surface de l'élément optique soit inférieure à 0,1 fois la longueur d'onde pour des rayons faisant un angle de 40 à 60° avec la normale.

2. Elément optique selon la revendication 1, dans lequel l'épaisseur de la couche (39) de ZnS est d'au moins 0,76 mm (0,03 pouce).

3. Structure stratifiée comprenant des couches de ZnSe (22) et de ZnS (39) qui ont été

chauffées à une température d'environ 700 °C et qui a une interface (41) entre ces couches, dans laquelle l'interface est suffisamment plane pour que l'aberration du front d'onde transmis pour les ondes qui ne sont pas perpendiculaires à la surface de la structure soit inférieure à 0,1 fois la longueur d'onde pour des rayons faisant un angle compris entre 40 et 60° avec la normale.

4. Procédé de préparation d'un élément optique infrarouge par dépôt chimique en phase vapeur de ZnS sur un substrat (22) de ZnSe à une température élevée, qui élimine la courbure de l'interface (41) provoquée par les coefficients inégaux de dilatation thermique de ZnS et ZnSe, caractérisé par les étapes suivantes :

l'établissement d'un régime de chauffage et de refroidissement pour le dépôt chimique en phase vapeur,

la détermination de la courbure de l'interface (41) pendant ce régime,

l'application d'une courbure inverse de cette courbure à la surface d'un substrat destinée à être au contact de ZnS, et

le revêtement du substrat de ZnS par dépôt chimique en phase vapeur,

si bien que l'interface obtenue entre ZnSe et ZnS est suffisamment plate pour que l'aberration du front d'onde transmis pour les ondes qui ne sont pas perpendiculaires à la surface de l'élément optique soit inférieure à 0,1 fois la longueur d'onde pour des rayons faisant un angle de 40 à 60° avec la normale.

5. Procédé selon la revendication 4, dans lequel le substrat est monté avant le dépôt d'une manière qu'il ne subisse aucune retenue longitudinale, latérale ni transversale.

6. Appareil de dépôt chimique en phase vapeur comprenant un four (28), une boîte (20) de mandrin montée dans le four et délimitant une zone (27) de dépôt en phase vapeur, la boîte ayant une plaque (31) de mandrin qui possède un passage (33) communiquant avec la zone de dépôt, un cadre (32) de support de substrat, monté de façon amovible sur la plaque de mandrin afin qu'il recouvre le passage et ayant une ouverture (34) qui est alignée sur le passage de la plaque de mandrin, et une plaque d'appui (36) montée de façon amovible sur la plaque du cadre de support comme organe de fermeture de l'ouverture, caractérisé en ce que le cadre (32) de support fait partie d'un ensemble à cadre de support de substrat et plaque d'appui sans retenue et possède des lèvres (35) dépassant les unes vers les autres aux limites opposées de l'ouverture (34), entre la zone de dépôt (27) et la plaque d'appui (36), les lèvres étant destinées à supporter un substrat (22) destiné à être placé dans l'ouverture (34), l'ouverture étant par ailleurs plus grande que le substrat destiné à être placé dans l'ouverture et la distance comprise entre les lèvres et la plaque d'appui étant supérieure à l'épaisseur du substrat.

7. Appareil selon la revendication 6, caractérisé en outre par des organes protecteurs (37) dépassant l'un vers l'autre des limites opposées du passage (33) formé dans la plaque de mandrin (31) vers la zone de dépôt et à distance du cadre de support (32).

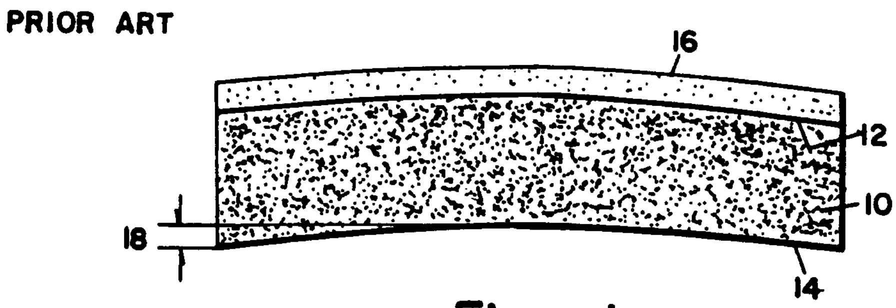

Fig. 1

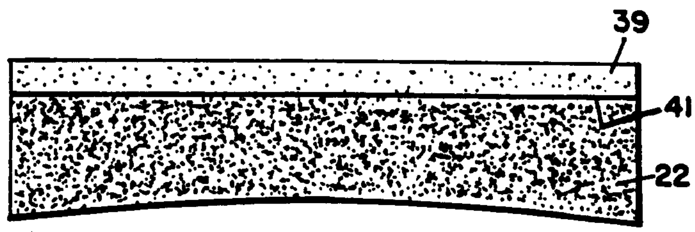

Fig. 7

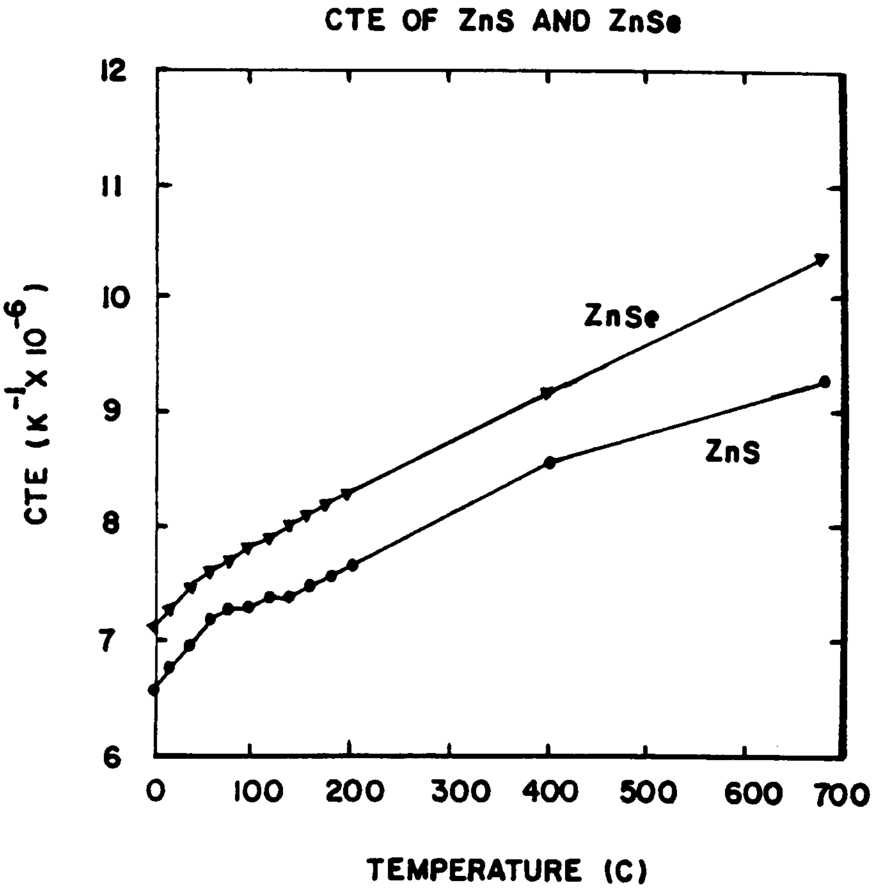

Fig. 2

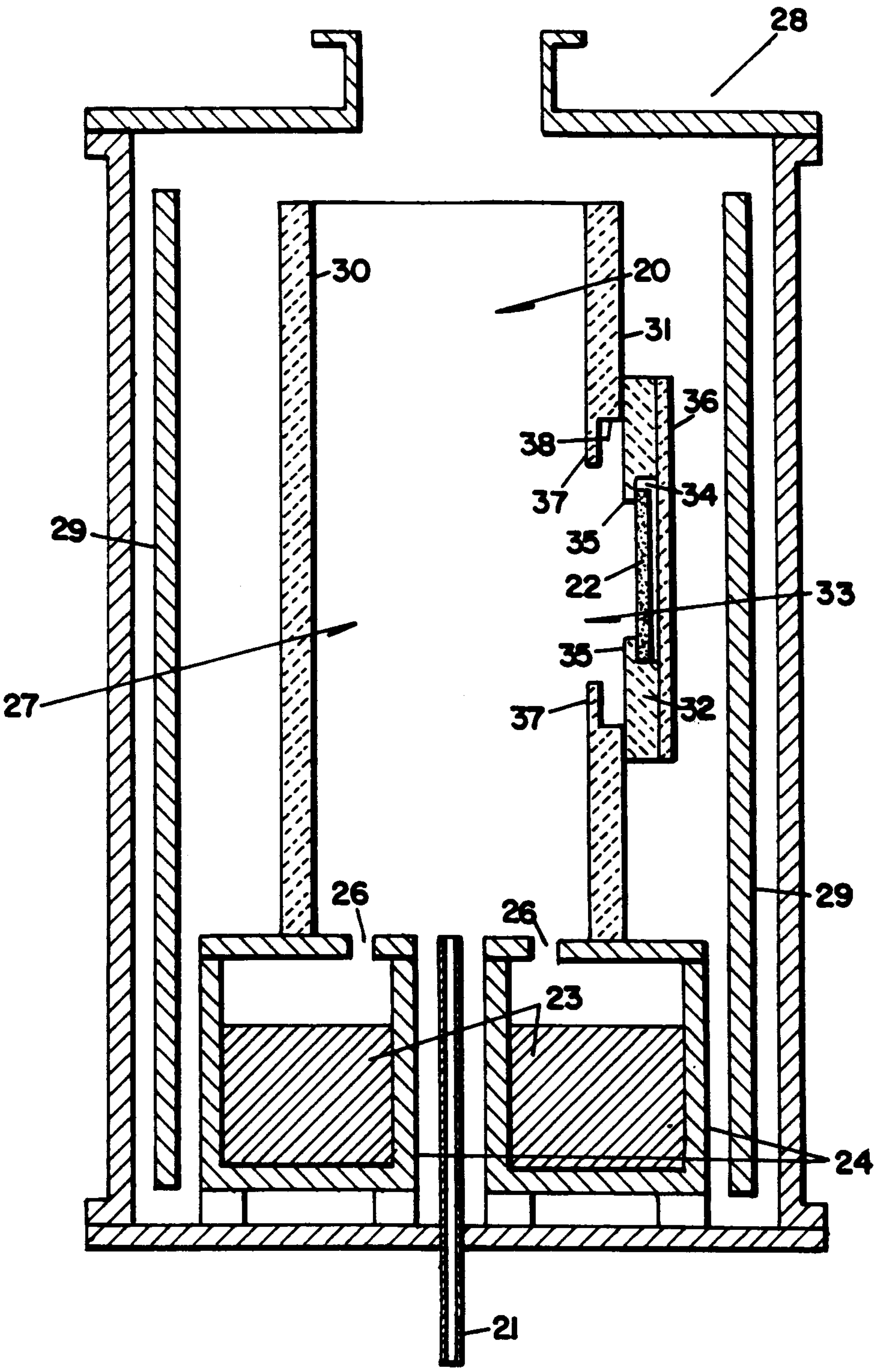

Fig. 3

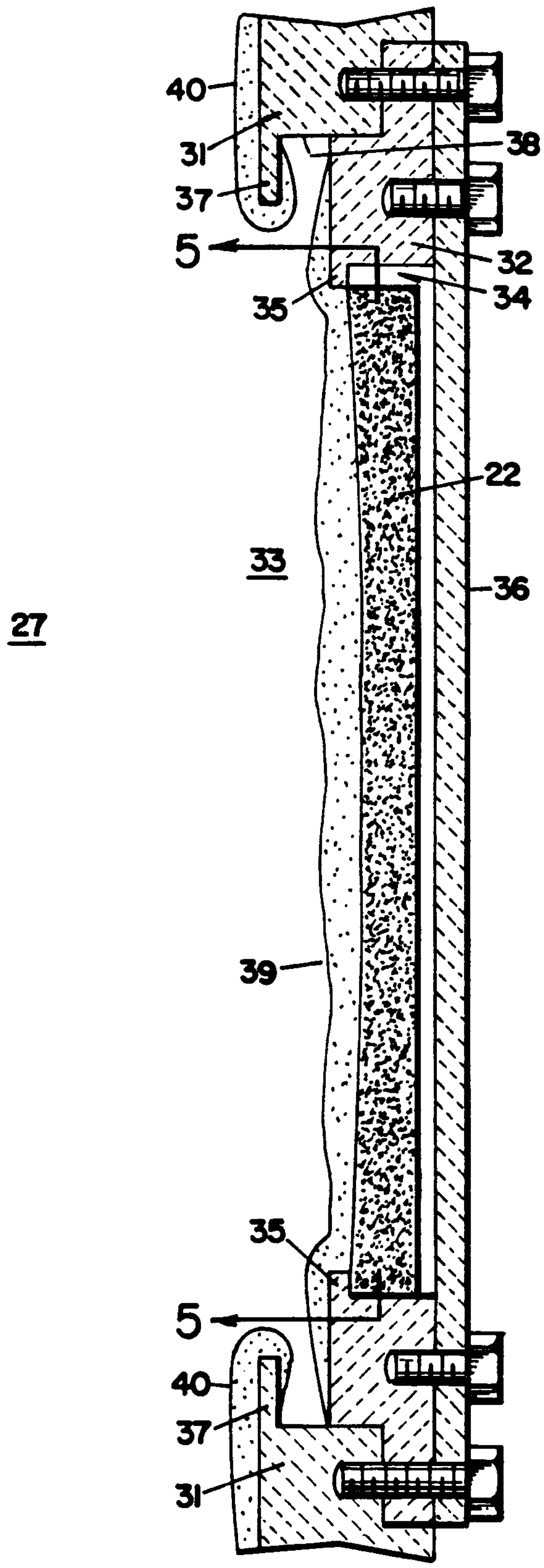

Fig. 4

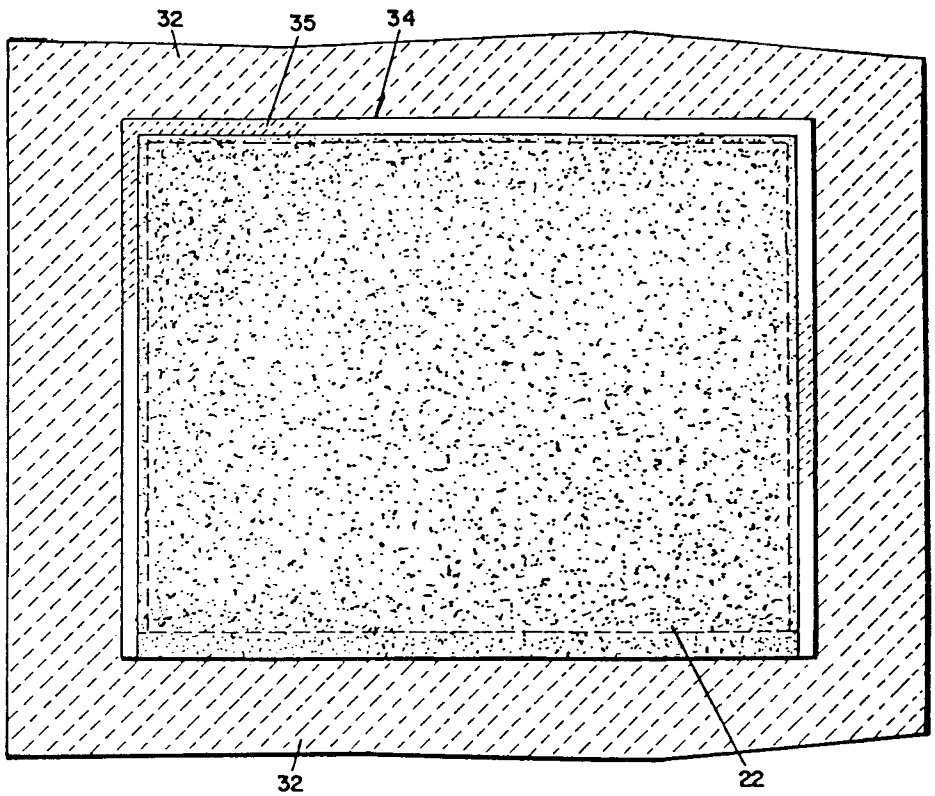
32
35
34
32
22

Fig. 5

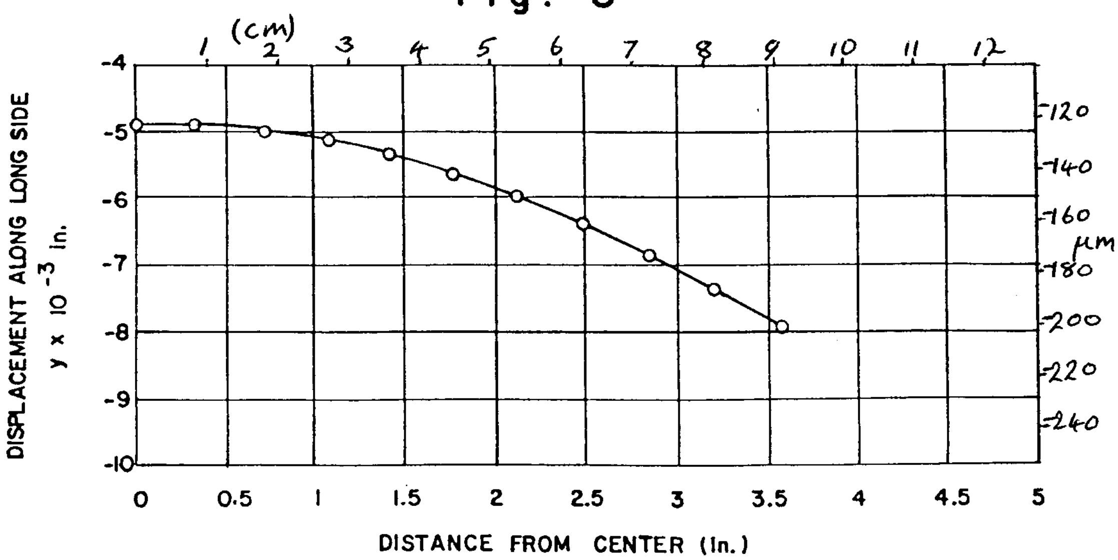
(cm)
1
2
3
4
5
6
7
8
9
10
11
12
-4
-5
-6
-7
-8
-9
-10
DISPLACEMENT ALONG LONG SIDE
y x 10 -3 In.
120
140
160
180
200
220
240
µm
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
DISTANCE FROM CENTER (In.)

Fig. 6